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The microstructure and hardness of casting a solid brake disc after late graphitizing modification

D A Boldyrev[1, 3], R R Dema[2] and O B Kalugina[2]

[1] Togliatti State University, 14, Belorusskaya Street, Togliatti City, 445020, Russia
[2] Nosov Magnitogorsk State Technical University, 38, Lenin Street, Magnitogorsk, 455000, Russia

E-mail: [3]denis.boldyrev@vaz.ru,

Abstract. The features of graphite formation in hypoeutectic and hypereutectic gray cast iron are considered. It is shown that this process in hypoeutectic gray cast irons is easier to control than in hypereutectic, because the formation of a predominantly rectilinear uniformly distributed graphite with a smaller size range and the presence of other distributions is achieved by an one-stage operation of ladle graphitization. The structure of graphite in hypereutectic gray cast irons is characterized by a large variety of its shapes, sizes and distributions, and it is also less technologically stable and controllable. Its characteristics can be approximated to the structure of hypoeutectic gray cast iron due to the obligatory second stage of graphitization. The microstructure and hardness of casting a solid brake disc after late graphitizing modification in a mold are investigated. The content of interdendritic distributions of graphite PGr8, PGr9 and short inclusions of graphite PGd45-90 (GOST 3443-87) was minimized due to the operation of the secondary (late) graphitizing modification. And Brinell hardness of the solid brake disc meets production requirements.

1. Introduction

The process of graphite formation and its features during crystallization of hypoeutectic gray cast irons (with a degree of saturation $Sc < 1$) has been studied in sufficient detail [1–3]. This type of cast iron is quite susceptible to graphitizing modification. In such cast iron, a graphite structure can be formed at a relatively low consumption of graphitizing modifier (<0.3% for ladle modification using the 'under a single batch' method) with the following generally recognized as the most favorable characteristics [4, 5]: PGf1 – PGr1 – PGd (45–180) – PG (6–10) according to Russian state standard GOST 3443–87.

The process of graphite formation of hypoeutectic gray cast irons is quite easily controlled and an one-stage ladle graphitizing modification is quite sufficient to obtain the above structure. Figure 1 shows a typical graphite structure from a hypoeutectic gray cast iron.

During crystallization of hypereutectic gray cast irons (with a degree of saturation $Sc > 1$), the process of graphite formation is more complicated, since it is less controlled by graphitizing modification. The favorable graphite structure (during an one-stage graphitizing ladle modification) is not achieved and has the following characteristics: PGf1,2 – PGr1,3,5 – PGd (45–350) – PG (10–12) according to GOST 3443–87 [6–9]. That is, a swirling shape also appears along with a rectilinear lamellar structure. Both colony of lamellar graphite and its branch distribution are added to the uniform distribution, and the range of lengths of graphite inclusions increases in the direction of their elongation. Below are the most characteristic microstructures of hypereutectic gray cast iron (Figure 2).

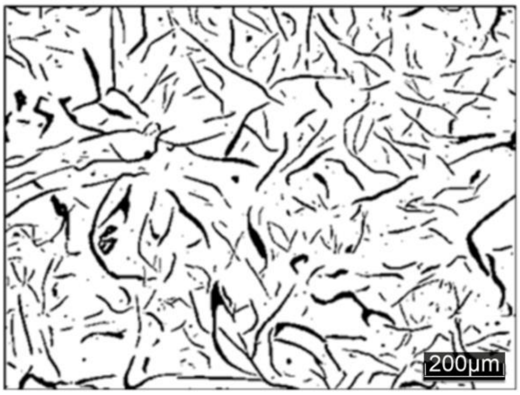
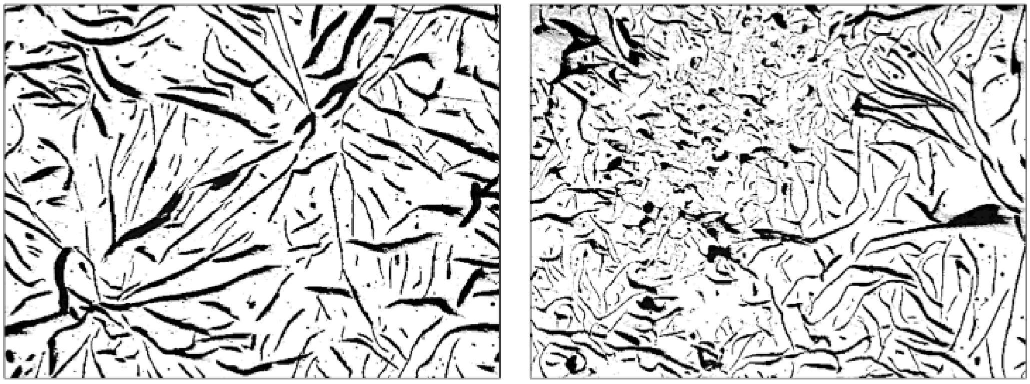


Figure 1. Typical structure in hypoeutectic gray iron castings (rectilinear lamellar structure).



a b

Figure 2. Typical structures in hypereutectic gray iron castings:
a – rectilinear; b – swirl.

This qualitative difference in the microstructure of graphite is explained by the crystallization features of hypoeutectic and hypereutectic gray cast irons. During crystallization of hypereutectic gray cast iron, the initiation of graphite formation occurs after and due to the introduction of a graphitizing modifier, which creates crystallization centers of graphite inclusions in quasi-eutectic zones locally saturated with silicon. A sufficient amount of a graphitizing modifier with a certain set of active elements (barium, calcium, strontium) completely removes the overcooling of the cast iron melt and allows forming a uniform distribution of PGr1 of rectilinear graphite inclusions PGf1 of an average length of 90–180 microns. A qualitative difference between the crystallization process of hypereutectic gray cast iron is the initial separation of primary graphite from the melt. The morphology of primary graphite is first and foremost formed by the introduced graphitizing modifier. Primary graphite after graphitization of cast iron in the ladle is a rectilinear plate PGf1 with uniform PGr1 and/or branch PGr5 distribution. However, the graphitizing effect of the initial modification to create a favorable graphite structure during eutectic transformation and lower temperatures, similar to the structure of hypoeutectic gray cast iron, is insufficient. As a result, colonies of PGr3 are formed in later crystallizing zones. Thus, the process of uniform structure formation of graphite after the eutectic transformation is violated, as evidenced by its crowding and thickening in the form of Pgr3 colonies, that is, it becomes uncontrollable. If the technology is not complied with regarding the consumption of the graphitizing modifier and/or the method of introducing it into the ladle, the described unfavorable graphite structure is supplemented by interdendritic (non-directional point PGr8 and directed lamellar PGr9) distributions.

2. Methods and Materials

The object of the study was the casting of solid brake disc from gray cast iron (the composition is shown below). Castings of brake discs are obtained as follows. The melt of hypereutectic iron (C 3.92 %, Si 2.00%, Mn 0.72%, P 0.02%, S 0.08%, Cr 0.29%, Ni 0.09%, Cu 0.60%, Sn 0.01%) is obtained in an induction crucible furnace and poured into a holding induction crucible furnace (holding furnace). The Barinoc® 75 modifier with a fraction of 2–6 mm was used during graphitizing ladle modification in an amount of 0.15% (1.5 kg per 1 ton of molten iron in the ladle), the chill hard spots was 1.5–1.6 mm (chill test). The molten iron temperature in the ladle was 1420 ^{o}C, the ladle casting time lasted 8 minutes. Lump Fs75-3 of 70–110 g was used for secondary (late) graphitizing modification.

The hardness was measured using a stationary Brinell hardness tester HB-3000B. The microstructure of cast iron was studied using a Metam RV-21 metallographic microscope for visual observation of the microstructure of metals, alloys, and other opaque objects in reflected light. Magnification of the microscope from 50 to 1000.

3. Result and Discussion

The approximation of the graphite structure of hypereutectic gray cast iron to hypoeutectic in terms of achieving its uniform distribution of PGr1 can be realized in one of two ways:

1) carrying out late graphitizing modification to the stream during the pouring of the mold, which is universally recognized as the most effective way;

2) carrying out, along with the primary graphitizing ladle modification, late graphitizing modification with cast or pressed intra-shaped inserts placed in a special socket located in the smudge sump under the sprue, or with a briquette from pressed siftings of ferrosilicon in the sprue well.

However, for the implementation of the first way, a specialized metering device is necessary, which is a complex, high-tech equipment due to its automated operation and control. There is also a restriction on the type of automatic molding production line – it should be with step-by-step conveyor movement (the automatic supply of the modifier from the dispenser does not work satisfactorily while filling the casting molds with molten iron from the ladle on lines with continuous conveyor movement).

The second way is technologically simple and convenient. However, cast inserts for all their effectiveness are quite expensive (≈1 euro/pc.) due to their making in complex chill molds, and pressed ones are characterized by instability of dissolution. The most technologically simple and economical way to carry out the operation of late graphitizing modification is to put lumpy ferrosilicon (usually Fs75 grade – GOST 1415–93) into a casting mold with a mass of ~0.05% of its metal consumption (mass of all castings together with a gate system and a sprue). According to this technology, a batch of pilot castings of brake discs was made. Figure 3 shows a photograph of a solid brake disc, and table 1 shows the results of a study of the microstructure and Brinell hardness of the casting in zones No. 1–4.

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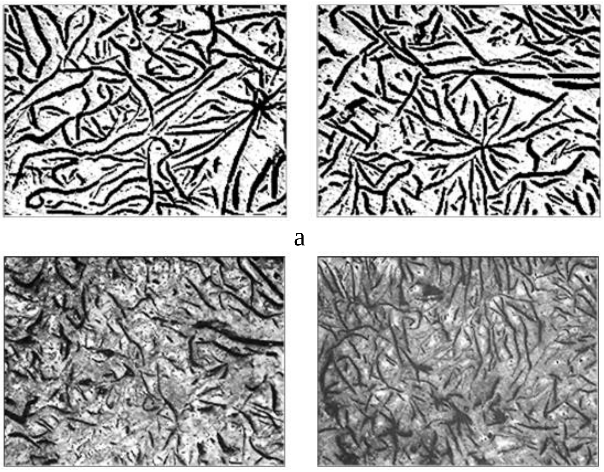
Figure 3. The solid brake disc casting with research zones No. 1–4.

Table 1. The microstructure and Brinell hardness of the solid brake disc casting.

No. zone	$HB_{5/750/10}$	Metal base,%			Graphite
		Perlite	Ferrite	Cementite	
1	187, 182, 179, 179, 185 Average 182	Basis	1	0	Non-massive zone PGr8 + PGr9 <5%, core PGd750. PGd45-90 <10% in the contact zone of the disc and brake pads and, partially, in the machining allowance zone, in the remaining zones PGd180–350
2	179, 179, 182, 179, 187 Average 181	Basis	1	0	Non-massive zone PGr8 + PGr9 <5%, core PGd750. PGd45-90 <10% in the contact zone of the disc and brake pads and, partially, in the machining allowance zone, in the remaining zones PGd180–350
3	179, 179, 177, 179, 187 Average 180	Basis	1	0	Non-massive zone PGr8 + PGr9 <5%, core PGd750. PGd45-90 <10% in the contact zone of the disc and brake pads and, partially, in the machining allowance zone, in the remaining zones PGd180–350
4	187, 187, 187, 180, 187 Average 186	Basis	1	0	Non-massive zone PGr8 + PGr9 <5%, core PGd750. PGd45-90 <10% in the contact zone of the disc and brake pads and, partially, in the machining allowance zone, in the remaining zones PGd180–350
Brake disc casting requirements					
	170–217	Basis	< 5	< 5	PGd180–350, Non-massive zone PGr8 + PGr9 <5%, core PGd759 or PGr7 <10%. Allowed in the contact zone of the disc and brake pads PGd180 <= 20 %, in other zones PGd180 <= 40%

Below are photos of microstructures obtained in zone No. 1 (Figure 4).



b

Figure 4. The microstructure of cast iron brake disc (enlarged ×100):
a – not etched; b – etched.

4. Conclusion

Thus, hypereutectic cast iron of the brake disc casting according to microstructure and Brinell hardness complies with the manufacturing requirements. The content of interdendritic distributions of graphite PGr8, PGr9 and short inclusions of graphite PGd45–90 was minimized due to the operation of the secondary (late) graphitizing modification in the microstructure of cast iron upon reaching the actual length of most graphite inclusions - no more than PGd350. The structure of hypereutectic gray cast iron with such characteristics provides the best combination of its antifriction and thermophysical properties.

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